

Regenerative braking with battery management system in E-bike

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Article Info

Article history:

Received Feb 9, 2025

Revised Jan 14, 2026

Accepted Mar 12, 2026

Keywords:

Battery management system

Braking mechanism

E-bike

Energy recovery

Regenerative braking

ABSTRACT

Energy neither be created nor be destroyed, but it can be transformed into other forms as per the law of conservation of energy. This information is epitomized by the regenerative braking system (RBS), which transforms kinetic energy into mechanical energy, thus recuperating waste energy into mechanical energy and making it beneficial. The regenerative braking have significant impact in electric vehicle technology due to the contemporary energy challenges and dwindling resources. Regenerative braking involves apprehending the lost kinetic energy during braking and converting it into a storable or instantly usable form. The recuperated kinetic energy can be reintegrated into vehicle's power system or stored for further use, often in a battery, especially lithium-ion batteries which are managed by a battery management system (BMS) to ensure optimal performance and longevity. The utilization of various sensors by BMS to monitor parameters such as temperature, current, and voltage, entitling it to assess the battery's health and determine its state of charge and discharge. Additionally, the BMS protects the battery against cavernous discharge and over-voltage, which can result from rapid discharging and charging currents, thereby optimizing the utilization of battery energy. In this article, the design of an electrical regenerative braking system with a battery management system in an electric bicycle (E-bike) applications are presented. The results show that the system works well in both battery-operated and regenerative modes. When in regenerative mode, the voltage and current stay within the specified range and are suitable for charging batteries. On the other hand, during regular operation, the increase in energy consumption is matched with the battery mode mileage.

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1. INTRODUCTION

Electric vehicles (EVs) contribute to sustainable commutes towards the globalization which leads to eco-friendly future. The EV factor influences the involvement of innovative technologies in association with the vehicle functionality, in addition to the energy efficiency and storage which leads to the continuous assimilation of regenerative braking systems [1]-[5]. The mechanical device attached with E-bike containing pedal drive which creates electric propulsion and also provides effective solution for the needs of comfortable riding. In spite of technical challenges (drive range and stability), the E-bike exhibits good

performance with the inclusion of components like drive motor, controllers, and storage facility. Numerous variants of motors with the maximum power output of 360 W and different voltage ratings (24/36/48 V) possess definite storage facilities with variable speed range [6]-[10]. The ascertained benefits of lithium-ion battery helpful to maintain the maximum power output and voltages. To ensure optimum E-bike efficiency and performance, the controllers are placed between drive motor and storage system which regulates the speed range and rider input. The energy generated from braking mode transforms into electrical energy which will be utilized in the future from the E-bike batteries. The working mechanism of E-bike battery depends upon the uncertainties related to battery's voltage, charge, discharge and heat sensitivity [11]-[15]. The prolonged battery life is assured with the integration of regenerative braking system (RBS) and battery management system (BMS) without any charging issues and efficient energy storage. This sophisticated system provides an effective blend of features, enhancing the performance, efficiency, safety, and longevity of electric vehicles [16]-[20]. The main aim of this article is design and implementation of RBS with BMS in electric bicycle and validation of the hardware system.

The optimization of energy recovery in various vehicle types and sizes is challenging. Due to inefficiency in battery replenishment, there is a challenge in optimize overall performance. In certain condition, variation in charging of the battery with the full potential of regenerative braking may not be realized. Exploring ways to optimize costs in the design, production, and implementation of regenerative braking without compromising performance is also a challenging aspect.

2. METHOD

2.1. Proposed system

The block diagram of the proposed system containing different components of battery management system in E-bike is depicted in Figure 1. The implementation of the regenerative braking system entails the utilization of a brushless DC hub motor with specifications of 24 V, 15 Ah, and 350 W, which is seamlessly integrated with the cycle wheel. To regulate the motor's speed, a 24 V, 350 W E-bike motor controller is employed as listed in Table 1. Additionally, a three-phase full-wave rectifier is connected to the motor's output, facilitating the conversion of incoming alternating current into direct current. The resultant DC current is then adjusted through the application of a buck-boost converter to appropriately charge the 24 V, 14 Ah lithium-ion battery. The motor can be operating in both directions; the proposed system adopted battery mode and regenerative mode. During the cycling motion, the motor draws power from the battery without altering its state. When braking is initiated, the motor transitions into a generator, generating a specific voltage. This voltage undergoes rectification and amplification before being directed towards the battery for recharging, effectively conserving energy and rejuvenating previously wasted energy. The utilization of electrical braking not only enhances energy efficiency and extends range but also minimizes wear on mechanical brakes. Furthermore, it enables the recovery of energy that would otherwise be dissipated during braking. Figure 2 shows the flow chart of regenerative braking mode with battery management system in E-bike.

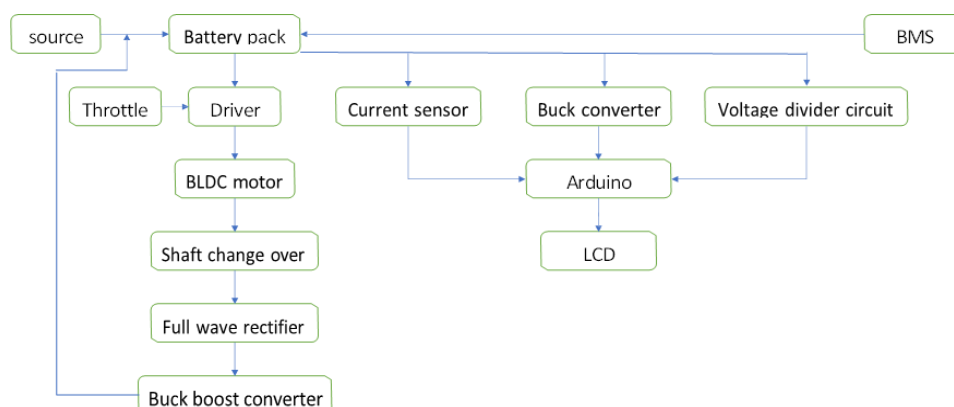


Figure 1. Block diagram of the proposed system

A 24 V, 15 Ah lithium-ion battery pack is engineered to power the motor. The battery pack comprises forty-nine 3.7 V, 2.2 Ah lithium-ion cells connected both in series and parallel. Lithium-ion batteries boast several advantages, including high energy density, extended cycle life, minimal self-discharge,

rapid charging capability, absence of memory effect, wide operational temperature range, lightweight and compact design, high discharge rates, low maintenance requirements, and eco-friendliness. To maintain cell balance and safeguard against overcharging and discharging, a battery management system board is linked to the pack. A current sensor is incorporated to prevent overcurrent issues, while a voltage divider circuit facilitates the measurement of individual series voltages within the pack, allowing for the determination of charge percentage based on battery voltage. Furthermore, a temperature sensor is integrated to monitor battery temperature. These parameters, including voltage and current during regular usage and regeneration, are exhibited on an LCD display. Control of all these sensors is managed by an Arduino Uno microcontroller.

Table 1. Specifications of proposed regenerative mode

Sl.No.	Parameters	Specifications
1	Current breaking	14 A
2	RPM	500 (average)
3	Regenerated power (PR)	350 W (average)
4	Regenerated voltage	24 V
5	Energy recovery efficiency (η)	>83%

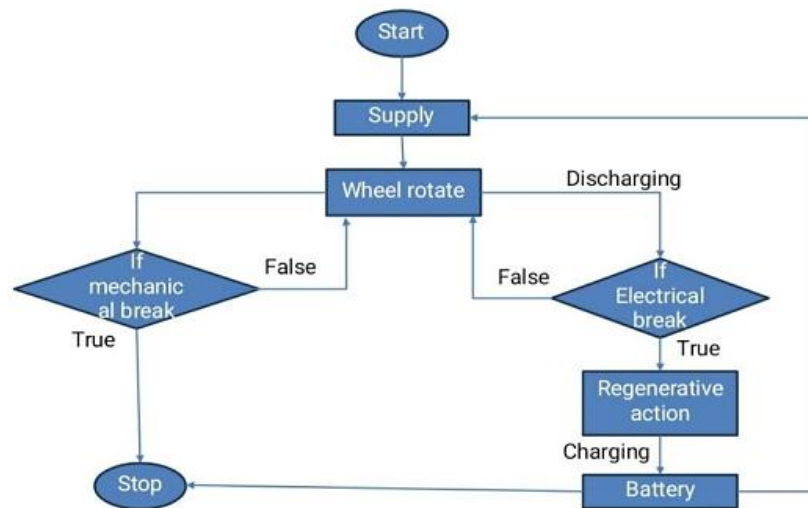


Figure 2. Flow chart of regenerative braking mode with battery management system in E-bike

2.2. Battery management system

The block diagram of the battery management system is shown in Figure 3. Regenerative braking is a unique feature revolutionizing the efficiency and range of electric bicycles (E-bikes). This method, when combined with an advanced BMS, allows kinetic energy to be converted into electrical energy during braking, which is then stored in the battery for later use. The circuit connection of the proposed E-bike system is as shown in Figure 4.

The scenario is initiated when the rider starts the E-bike and apply the brakes. The sensors attached with the brakes alarm the motor controller to start the RB. The upward momentum of E-bike generates electricity when the motor controller changed into generator phase and simultaneously the battery stores the converted energy (from AC to DC) without misfits leading to prolonged battery life and optimized performance. The incorporation of BMS in the RB improves efficiency with the support of reaction variables. The integration of these two systems contributes the sustained energy and effortless riding. The one limitation of this E-bike is that the loss of energy is ascribed to the repeated braking which creates friction and heat. An additional braking system is the anti-lock braking system. With this method, the vehicle is slowed down or stopped as needed through the use of intermittent braking rather than continuous braking. This technology offers better performance and is more efficient than the conventional brake system. When brake apply, the motor functions as a generator to slow down the vehicle and recharge the battery. The motor current produced while the vehicle is braking can alternatively be directed via a different circuit. These kinds of technologies also help with braking and charge the battery. Regenerative braking systems, however, they can only slow down a vehicle's speed and not fully stop it. The brake control sensor transfers the electrical energy produced by the motor toward the batteries when braking. The regenerative braking systems are

a significant development in E-bike technology that combine sustainability with performance in a way that will completely change urban mobility in the future. Arduino Uno is used as a microcontroller to control all the sensors and battery management system.

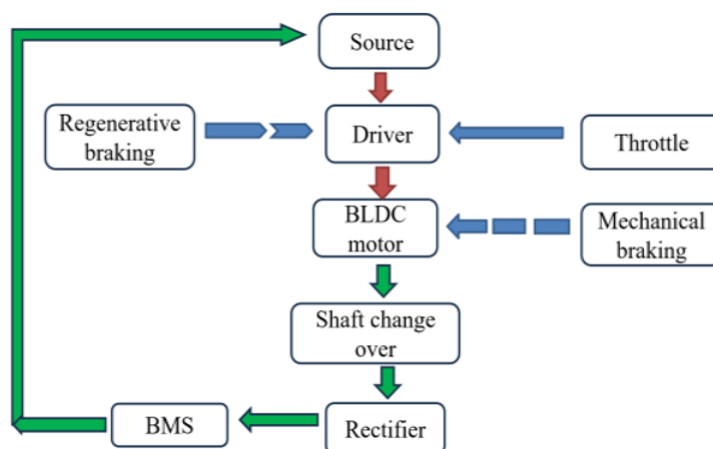


Figure 3. Block diagram of battery management system

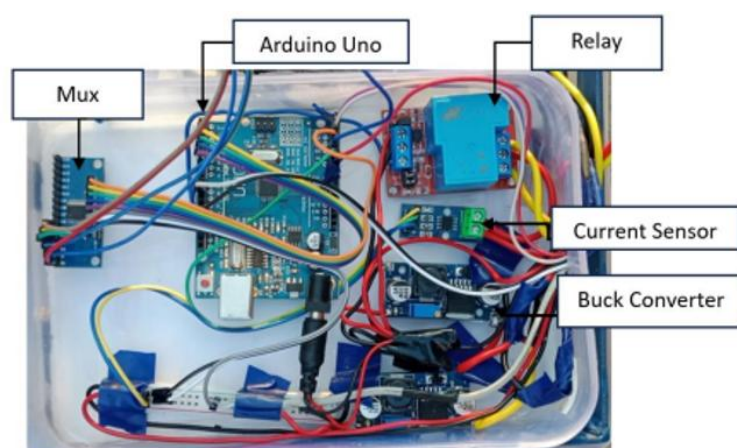


Figure 4. Wiring diagram of battery management system

3. RESULTS AND DISCUSSION

The hardware of the proposed E-bike system is shown in Figure 5. The regenerative braking mode was evaluated by the applying brake to supply voltage into the battery. The results of the battery mode and regenerative braking modes are displayed in Tables 2 and 3. Different speeds were applied, and each mode test was repeated. With an increase in distance, the current also proportionally increases. Hence, it shows that regenerative braking meets the specified requirements of battery.

Table 2. Voltage variation with respect to distance in the absence of regeneration

Distance (km)	Voltage	Current
0	24	0.01
1	23	0.09
2	22.9	0.1
3	22.0	0.6
4	21.0	0.9
5	20.9	1.0

Table 3. Voltage variation with respect to distance during regeneration

Distance (km)	Voltage	Current
0	24	0.1
1	23.8	0.2
2	23.85	0.26
3	23.90	0.32
4	23.98	0.32
5	23.70	1.03
10	23.30	4.02
15	21.09	8.70

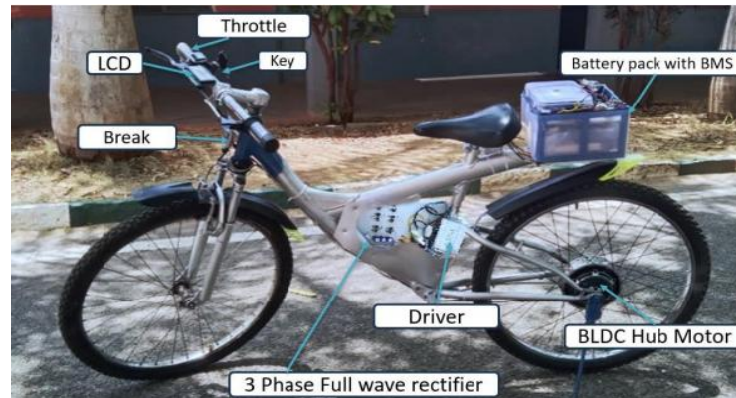


Figure 5. Hardware model of the proposed E-bike

State of health (SOH) of the battery pack measures current, voltage and temperature. Current is measured by ACS712 current sensor and voltage is measured in each series of the battery pack by using voltage divider circuit. Battery temperature is measured by temperature sensor, if the temperature is exceeded above the limit, then cooling system turns on, starts to reduce the temperature in the battery pack. State of charging of battery pack is measured by using the value of voltage, if the voltage in the battery is 24 V, then it is charged completely. According to the voltage in the battery charging and discharging is measured. All the values of these parameters are displayed in the LCD display of BMS (Figure 6).

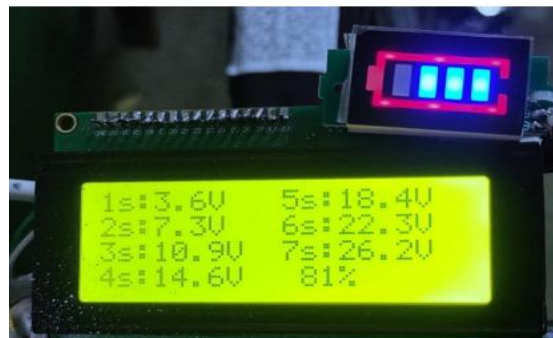


Figure 6. BMS parameters shown in LCD display

3.1. Comparative analysis

The design of an electrical regenerative braking system with a battery management system in E-bike with brushless DC hub motor with specifications of 24 V, 15 Ah, and 350 W is presented. The results show that the system works well in both battery-operated and regenerative modes. In regenerative mode, the voltage and current stay within the specified range and are suitable for charging batteries when compare to large power ratings electric bicycles [21]-[25]. On the other hand, during regular operation, the increase in energy consumption is matched with the battery mode mileage. The main components of the electrical regenerative braking system function flawlessly.

4. CONCLUSION

The results depict the influence of RBS and BMS technology in the application of E-bike. The RB mode decides the desired range of battery charge to meet the required voltage and current ratings. In the stationary riding mode, the energy consumption is minimal and in the accelerated mode, it is vice versa. The central component of E-bike, such as RBS works effectively in storing and transforming energy when the braking mode is operated in relative comparison with the other modes. The variation of average voltage and current ratings are not significant enough to affect the performance of the battery. The movement of E-bike connected to the velocity which is proportional to the current. The ratings complied with the RBS highlights the generated current is crucial and which will not deteriorate the quality of the battery life skeptically.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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